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Are the outcomes of bone transport in the treatment of bone defects in the upper- middle and lower-middle tibia similar?

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The aim of the study was to compare the outcomes of bone transport in treating upper- middle vs. lower- middle tibial bone defects. Sixty-two patients with tibial infected large segmental defects treated by bone transport were analyzed retrospectively and divided into distal group (lower- middle tibial bone defects and proximal transport, n=38) and proximal group (upper- middle tibial bone defects and distal transport, n=24). The demographic data were not significant different (P > 0.05). External fixation index (ETI), bone defect union time (BDUT), regenerate consolidation time (RCT), bone healing and functional outcomes evaluated by Association for the Study and Application of the Methods of Ilizarov score, postoperative complications evaluated by Paley classification, and the American Orthopaedic Foot and Ankle Society (AOFAS) score were recorded and compared at a minimum follow-up of 20 months. There were no significant differences in flap repair, follow-up time, ETI, RCT, bone healing, functional outcomes and complications between the two groups (P > 0.05). However, in the distal group, the BDUT was significantly longer, and the AOFAS score was significantly lower than those in the proximal group (17.5±2.5 vs 15.9±3.1 months, 70.0±5.5 vs 72.8±4.8, respectively) (P < 0.05). The overall outcomes of bone transport in treating upper- middle vs. lower- middle tibial bone defects are similar. However, the upper- middle tibia bone defects heal faster than the lower- middle tibial bone defects, and distal transport has a greater adverse effect on the ankle and foot joints than proximal transport. Therefore, traditional distal tibial transport near the ankle joint should be taken with caution.

Keywords: bone defects, bone transport, external fixator, complications, osteotomy, proximal, distal.

INTRODUCTION

Large segmental bone defects caused by severe trauma, bone infection and tumor are common in clinical practice. Vascularized bone grafting, Ilizarov technique and Masquelet induced membrane technique are the most commonly used treatment methods[1-3]. Ilizarov technique bone transport based on the principle of distraction osteogenesis achieves osteogenesis through gradual and continuous axial distraction and compression has become a popular method because of its simplicity, no need for bone grafting and simultaneous resolution of all possible pathologies, including infection, bone and soft tissue defects and alignment[4-7].

The osteotomy site mainly depends on where the defect focus is located. Distal osteotomy (distal transport) is usually performed for bone defects in the upper- middle of the tibia while proximal osteotomy (proximal transport) is usually performed for bone defects in the lower- middle of the tibia[8-10]. The effectiveness of bone transport in treating tibial defects should include healing of the docking site, osteogenesis in the distraction zone and the impact of traction on soft tissue. However, reports on the comprehensive effects of bone transport are rare, and there is even controversy over whether the effectiveness of proximal tibial transport is superior to that of distal tibial transport. Chen G et al.[11] reported that when bone transport was used to treat bone defects caused by debridement of tibial osteomyelitis, there was no significant difference in the effects of proximal tibial transport vs. distal tibial transport on distraction osteogenesis of the transport zone and bone healing of the docking site, but distal tibial transport had greater adverse effects on ankle function than the proximal tibial bone transport. Liu K et al.[12] also conducted a study on 236 patients with tibial bone defects treated using the Ilizarov external circular fixator, and their results showed that the incidence of postoperative ankle OA was 20.8 %, and the top five risk factors of postoperative ankle OA included double-level bone transport, EFI > 50 days/cm, age > 45 years, osteoporosis and BMI > 25. However, there was no significant difference between distal and proximal osteotomy for postoperative ankle OA.

For above, the purpose of this study was to compare the outcomes of bone transport in the treatment of upper- middle vs. lower- middle tibial bone defects.

MATERIALS AND METHODS

Inclusion criteria were as follows: (1) tibial defect > 4.5 cm after thorough debridement caused by infection or fracture with infection; (2) positive intraoperative culture or histology supporting a deep infection; (3) treated by single level tibial bone transport for reconstruction of bone defects; (4) follow-up time was more than 20 months. Exclusion criteria were as follows: (1) age under 18 years old or over 75 years old; (2) severe osteoporosis (Singh index I-III); (3) shortened replantation patients; (4) failed limb salvage; (5) external fixator was immediately changed to internal fixator after the docking site was closed; (6) incomplete medical records; (7) poor compliance.

The study was approved by the hospital's Ethics Committee and performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Signed informed consent was obtained from each patient. From January 2009 to December 2020, a total of 74 patients underwent bone transport technique. Of these, 12 patients were lost to last follow-up, and the remaining 62 patients were included in this retrospective study. There were 39 males and 25 females with mean age of 41.1±13.2 years (range, 19-73 years). According to the bone defect site, the patients were divided into 2 groups: distal group (bone defects located in the lower- middle of the tibia and proximal transport was performed, 38 cases) and proximal group (bone defects located in the upper- middle of the tibia and distal transport was performed, 24 cases). All patients were given antibiotic therapy. The demographic data including gender, age, defect site, BMI, smoking, diabetes, infection mode, infection duration, external fixator type, bone defect length, soft defect, number of operations, and foot drop are shown in Table I showing no significant difference between the two groups (P > 0.05).

The patients were placed in a supine position on a radiolucent table under continuous general or spinal anesthesia. The anterolateral longitudinal incision or incision along the previous surgical scars or consistent with preoperative flap design was performed, cutting and separating subcutaneous tissue to explore the infected bone.

Radical debridement was performed by removing at least 0.5 cm away from the infected or devitalized bone and soft tissues until reaching healthy bleeding bone (paprika sign) with adequate soft-tissue cover. All implants or external fixation devices placed previously

Table I. — Comparison of demographic data between two groups

Variables	Distal group *(n = 38)*	Proximal group *(n = 24)*	*P* value
Age (years)	41.2±12.8	40.8±14.0	0.929
Gender (M/F)	24/14	15/9	0.958
Side(L/R)	17/21	11/13	0.933
BMI>24	1	1	0.628
Smoking	16	7	0.420
Diabetes	5	3	0.940
Infection mode (infective fracture/osteomyelitis)	27/11	18/6	0.734
Infection duration (day)	87.8±24.5	90.8±24.5	0.636
External fixator type (annular/unilateral)	29/9	18/6	0.906
Bone defect length (cm)	6.9±1.5	7.0±1.5	0.929
Soft defect(cm^2)	45.8±17.5	37.0±18.0	0.064
Number of operations	2.7±0.8	2.8±0.9	0.335
Foot drop	7	4	0.572

were removed. Samples from the infected area were obtained for bacterial culture and histological analysis to guide the postoperative antibiotics. Irrigate the wound with hydrogen peroxide solution, 0.9% normal saline, and iodophor saline solution during and after debridement. One stage or staged skin flap repair for soft tissue defects after resection were performed, which was depending on the residual infection and defect size consideration evaluated by an experienced surgeon. In some patients, we used antibiotic loaded bone cement spacer (2 g vancomycin per 40 g of cement) in staged procedure.

According to the actual situation of the patient and the surgeon's habits, a unilateral or annular external fixator was used. The pin or half-screw needs to cross the transport bone segment while maintaining the normal alignment of the affected limb and the ankle joint in a neutral position. When using an unilateral external fixator, placing 3 half-screws at the proximal and distal end of the tibia, respectively, and finally connecting the external fixation bracket; when using an annular external fixator, inserting 2 to 4 pins through the distal tibia parallel to the plane of the ankle joint and through the proximal tibia parallel to the plane of the knee joint, respectively, and then connecting the Ilizarov ring with a threaded rod. In cases complicated with ankle joint deformity, correction of the deformity were performed using external fixation at the same time. During the operation, needle placement was performed in strict accordance with the safe passage technique, and the limb force line was confirmed by C-arm fluoroscopy.

Tibial osteotomy was performed using a minimally invasive drilling osteotomy procedure through a 3 cm long transverse incision at the junction between the tibial metaphysis and the diaphysis, stripping the soft tissue outside the periosteum, drilling the tibial diaphysis, cutting the bone use an osteotome, and finally suturing the wound.

A local propulsive or transfer skin flap, or vascularized free flap was utilized to cover the wound.

All patients were given antibiotics after surgery, and antibiotics were changed according to the results of bacterial culture for at least 6 weeks. The pins or half-screws were disinfected with 75% alcohol twice a day until no obvious exudation was found, then changed to once a day. Patients were encouraged for passive knee and ankle joint exercise on postoperative day one; Isometric contraction joint activity and partial weight-bearing exercises were started from the second postoperative day. Bone transport at the osteotomy site was commenced 1 week after osteotomy at an average rate of 1 mm/day. It was carried out 4 times, 1/4 mm each time at day time and the distraction was continued until the docking was closed. Patients were followed up regularly. Axial deviations were first corrected by adjusting the external fixator. Surgical intervention was only performed on patients who have failed to the correction by adjusting the external fixator. When there was malformation or/and dysplasia of the distraction osteogenesis, surgical intervention was performed (correction, bone grafting and plate osteosynthesis). When there was no radiological progression for 3 months after closure of the docking site or/and 2 months after application of accordion technique, indicating nonunion, surgical intervention was performed (removal of external fixator, application of a plate and bone grafting). When radiological examination showed bridging callus appeared at the docking site and mineralization of the distraction osteogenesis, the external fixator was removed after one month of dynamization, and a plaster cast was applied after removal of external fixation for 5-6 weeks.

Outcome evaluation

Outcomes were evaluated by the following parameters: (1) external fixation index (ETI, external fixation time/ length of tibial bone defects); (2) bone defect union time (BDUT, defined as time needed for the appearance of radiographic presence of bridging bone identified on 3 of 4 cortices without gross motion or tenderness at the site of bone defect with physical examination); (3) regenerate consolidation time (RCT, defined as total time needed for the appearance of consolidation of at least three cortices on the anteroposterior and lateral radiographs)[13]; (4) postoperative complications including recurrence rate of deep infection, delayed union or nonunion and complications related to Ilizarov technique according to Paley classification[14]; (5) bone healing and functional grades according to Association for the Study and Application of the Methods of Ilizarov (ASAMI) score of the lower extremity[15]; (6) American Orthopaedic Foot and Ankle Society (AOFAS) score[16].

Statistical analysis

Data were analyzed by the SPSS 20.0 software package (Chicago, IL, USA). For measurement data with normal distribution, they are expressed as $\bar{x} \pm$ s, and independent samples t-test was used. Otherwise, the U-test was used. For qualitative data, the Chi-square test or Fisher's exact test was used. $P < 0.05$ was considered to be statistically significant.

RESULTS

There was no significant difference in flap repair ($P > 0.05$) between the two groups. All patients were followed up, the follow-up time in the proximal and distal groups were 26.5 ± 3.7 months and 25.6 ± 3.8 months, respectively, showing no significant difference ($P > 0.05$).

The BDUT in the distal group (8-18 months) was longer than that in the proximal group (8-20 months), showing significant difference ($P < 0.05$). The EFI, RCT in the proximal and distal groups were not significantly different [(56-80 d/cm) vs. (55-81 d/cm) and (190-262 days) vs. (188-252 days), respectively, $P > 0.05$].

The excellent and good rate of bone and functional recovery in the distal and proximal groups were 84.2% vs 83.3%, and 73.7% vs. 83.3%, respectively, showing no significant difference ($P > 0.05$). The AOFAS score in the distal group (72.8±4.8) was higher than that in the proximal group (70.0±5.5), showing significant difference ($P < 0.05$). The outcomes are summered in Table II.

Rates of pins tract infection or pin loosing, muscle contracture or joint stiffness, malalignment, delayed ossification or re-fracture of the callus distraction zone, soft tissue incarceration, delayed union, nonunion, equinovanus, deep infection recurrence, and total complications in the distal group were 70.8%, 20.8%,

Table II. — Comparison of outcomes between two groups

Variables	Distal group (*n*=38)	Proximal group (*n*=24)	*P* value
Flap repair (propulsive/transfer/ vascularized free)	10/19/9	5/13/6	0.886
Follow-up time (M)	27.5±3.7	26.6±3.8	0.389
BDUT (M)	17.5±2.5	15.9±3.1	0.041
RCT (days)	219.9±19.4	224.5±23.2	0.407
EFI (day/cm)	69.3±3.7	67.3±4.2	0.061
ASAMI			
Bone grade (excellent/good/fair/poor)	17/15/6/0	11/9/4/0	0.987
Function grade (excellent/good/fair/poor)	13/15/8/2	10/10/3/1	0.832
AOFAS score	72.8±4.8	70.0±5.5	0.041
Surgical intervention	15	6	0.284

Note: BDUT bone defect union time, RCT regenerate consolidation time, EFI external fixation index.

Table III. — Comparison of complications between two groups

Complications	Distal group (*n*=38)	Proximal group (*n*=24)	*P* value
Pin loosing or pin tract infection	28	17	0.806
Joint stiffness or muscle contracture	4	5	0.264
Malalignment, delayed ossification or re-fracture of callus distraction zone	5	2	0.559
Soft tissue incarceration	3	2	0.649
Delayed union	7	4	0.860
Nonunion	12	4	0.191
Equinovanus	2	1	0.845
Deep infection recurrence	2	1	0.669
Total/Per-patient complications	63/1.7	36/1.5	0.463
Surgical intervention	15	6	0.241

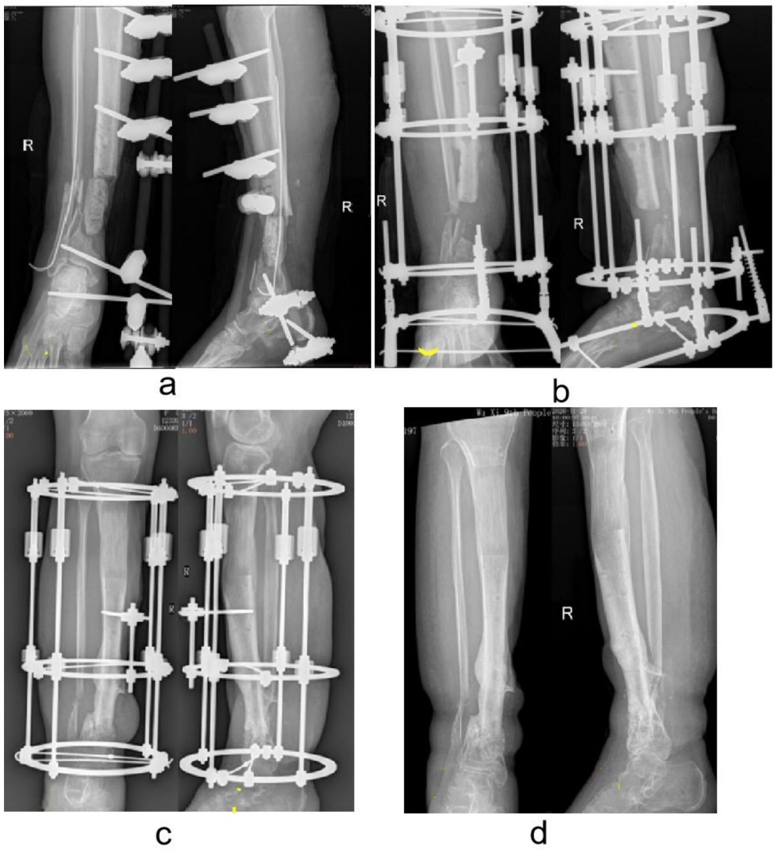

Fig. 1. — A 45-year old male patient with distal tibial fracture and defects was treated by proximal transport. (a) X-rays showing bone cement spacer filling the bone defects before bone transport. (b) X-rays showing proximal transport performed. (c) X-rays showing union of the bone defects and consolidation of the distraction osteogenesis. (d) X-rays showing removal of the external fixator.

8.3%, 8.3%, 12.5%, 12.5%,8.3%, 4.2% and 146%, respectively, while in the proximal group were 73.7%, 10.5%, 13.2%, 7.9%, 23.7%, 15.8%, 7.9%, 5.3% and 155%, respectively, showing no significant difference ($P > 0.05$). 15 cases including 2 cases with equinovanus, 12 cases with nonunion at the docking site and 1 case with recurrence of deep infection underwent surgical intervention in the distal group while 6 cases including 1 case with equinovanus, 4 cases with union at the docking site and 1 cases with recurrence of deep infection underwent surgical intervention in the proximal distal group, showing no significant difference between the two groups ($P > 0.05$). The complications are summered in Table III. Typical cases are showed in Figures 1-3.

DISCUSSION

This study aimed to evaluate the comprehensive effectiveness of bone defects located in the upper- middle and lower- middle of the tibia treated by bone transport including healing of the docking site, osteogenesis in the distraction zone and the impact of traction on soft tissue. In this study, the primary bone union rate of the docking site was 75.8%, the per-patient complication was 1.6, the most common complication was pin tract infection or/and pin loosening (72.6%), and the excellent and good rate of function was 77.4%, which were comparable to the studies in the literature[8-10,17,18], supporting the viewpoint of the effectiveness of Ilizarov bone transport in treating large segmental bone defects. Yin et al.[17] conducted a systematic review and meta-analysis of Ilizarov technique for the treatment of infectious tibia and femur nonunion including a total of 590 patients from 24 studies. Statistical analysis revealed an average tibial bone defect length of 6.54 cm, an external fixation index of 1.64 months/cm, and 1.23 complications per patient with infected tibia nonunion; Aktuglu K et al.[8] conducted a narrative review including 619 patients with critical-sized tibial bone defects treated by Ilizarov bone transport. The external fixation time was 10.75 (range 2.5-23.2) months. The

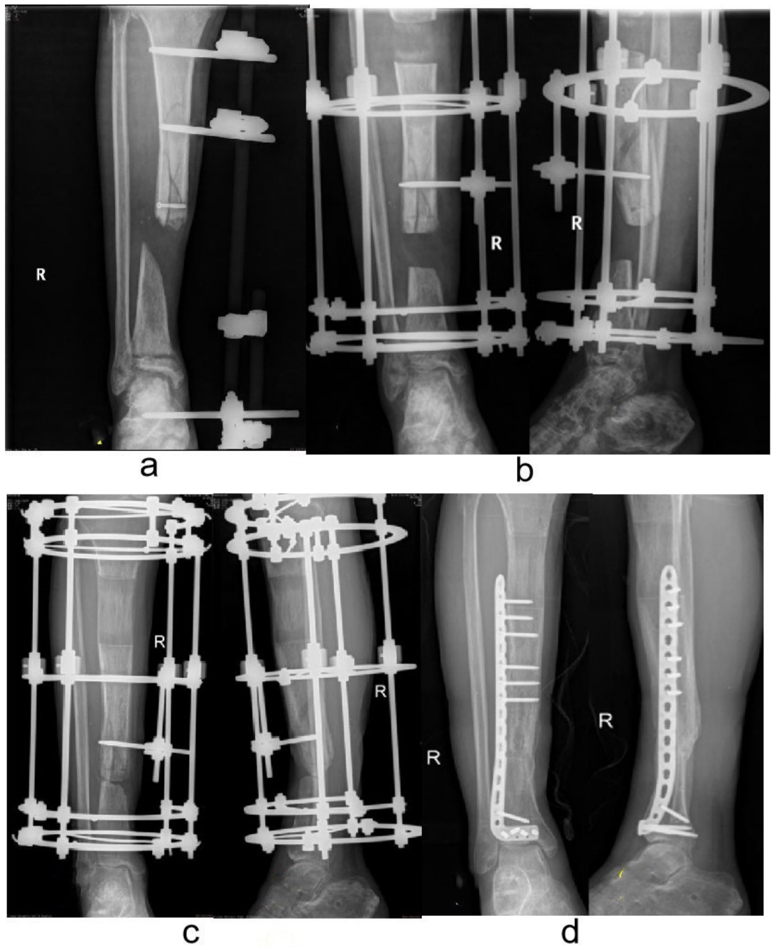

Fig. 2. — A 53 year old female patient with distal tibial fracture and defects was treated by proximal bone transport. (a) X-ray showing distal tibial defects before bone transport. (b) X-rays showing staged proximal tibia transport performed. (c)X-rays showing consolidation of the distraction osteogenesis and nonunion of the bone defects. (d) X-rays showing union of the bone defects after surgical intervention.

mean bone union rate was 90.2% (range 77-100)%. The excellent and good rate in bone healing and functional recovery were 88.8% and 82.6%, respectively. Mean complication rate per patient was 1.22 (range 3-60). The most common complication was pin tract infection (46.6%), followed by joint stiffness (25%).

The distraction osteogenesis and mineralization of the distraction zone is mainly related to the distraction rate [11,13]. Therefore, the RCT and malalignment, delayed ossification or re-fracture of the callus distraction zone between the two groups were not significantly different. Our study supports previous research conclusion that distraction osteogenesis in the distraction zone is not a problem, but the healing of the docking site is[13,18-20].

The main difficulty of bone transport for large segmental defects lies in the healing of the docking site[21]. Difficult healing of the docking site requires long term use of external fixator leading to many complications, such as loosening and infection of the pin tract, as well as joint stiffness[22]. The healing of the docking site is mainly related to the closing time and contact surface of the broken ends, location, including feeding arteries, abundance degree of surrounding soft tissue and soft tissue incarceration[21,22], of which, location is an important factor affecting bone healing. The proximal 1/3 of tibia has high density of muscles, nourishing blood vessels and wide contact surface of the broken ends, so the bone defect ends in the proximal 1/3 of tibia heal quicker than that in the distal 1/3 of tibia, which has been verified by a large number of clinical tibial fracture cases. In the study, the BDUT in the distal group was longer than that in the proximal group, showing significant difference ($P < 0.05$), which was in line with the above theory.

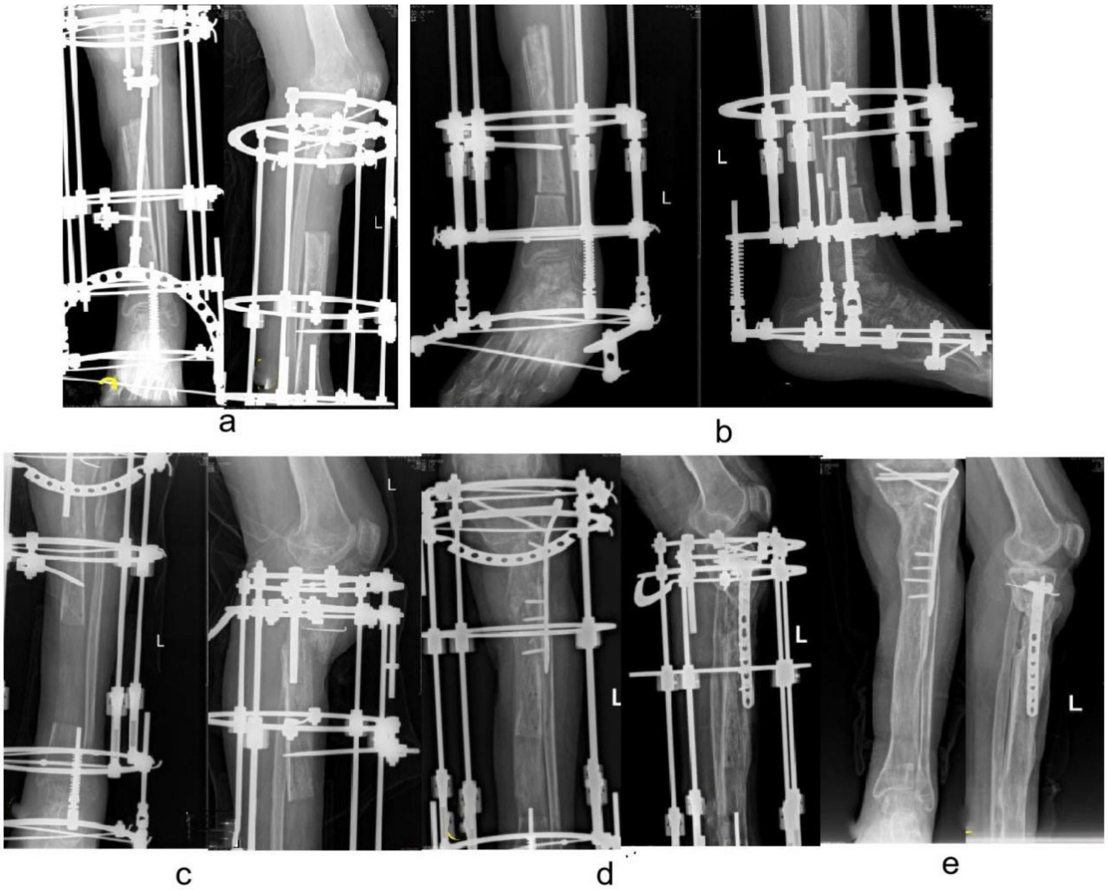

Fig. 3. — A 25 year old male patient with proximal tibial fracture and defects was treated by bone transport. (a) X-rays showing proximal tibial defects. (b) X-rays showing distal tibial transport performed. (c) X-rays showing malalignment (failed to the correction by adjusting the external fixator) and nonunion of the bone defects. (d) X-rays showing union of that the bone defects after surgical intervention. (e) X-rays showing removal of the external fixator and bony union.

The effects of bone lengthening on tendons and muscles vary. Study[23] showed that when the lengthening of the lower- middle calf exceeds 31.5% to 42.2% of the original limb length, it would lead to obvious foot and ankle dysfunction in patients, which may be related to the stretching speed, the imbalance of the calf flexor and extensor muscles during the lengthening process, axis line offset, etc. The impact of bone transport on ankle and hind foot function is similar to limb lengthening, but smaller. Paley et al.[14] pointed out that needles that passing through the calf through the fascia or tendon structures are more likely to cause peripheral joint contractures than through the muscles, which may be related to the poor compliance of the tendons and fascia. Therefore, the transport bone segment located at the distal end of the tibia (proximal group) where mainly composed of tendon tissue such as the Achilles tendon with less extensibility, is prone to cause foot drop and ankle joint contracture. The AOFAS score in the proximal group (70.0±5.5) was lower than that in the distal group (72.7±3.9) showing significant difference ($P < 0.05$), which was similar to the reports by Chen G[11].

In the study, the complications were not significantly different between the two groups, and the incidence of complications was similar to that reported in the literature[7-11,15]. The results indicate that more complications and higher incidence of complications are inherent defect of Ilizarov technique and does not significantly differ due to different osteotomy sites. But on the other side, the good news is that most of the complications are mild. In order to reduce complications, improved bone transport have emerged, such as one stage double-level (trifocal technique) or multilevel bone transport for large segmental bone defects[13,23,24], and application of a plate after the docking site closure[21,22,25], which can shorten external fixation time and healing time of the docking site, and reduce complications. In view of distal tibial transport has a greater adverse effect on the ankle and foot joints, traditional distal tibial osteotomy near the ankle joint should be used with caution and should be replaced by osteotomy near the middle to reduce adverse effect.

Limitations of the study

This is a retrospective and single-center study with a lower evidence level than a prospective multi-center study of large samples. Whether there were more ankle problems with the use of circular frames versus unilateral fixation remains to be explored.

CONCLUSION

The overall outcomes of bone transport in the treatment of bone defects in the upper- middle and lower- middle of the tibia are similar. However, the bone defects in the upper- middle tibia heal faster than those in the lower- middle tibia, and distal tibial transport has a greater adverse effect on the ankle and foot joints than proximal tibial transport. Therefore, traditional distal tibial transport near the ankle joint should be taken with caution.

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Consent to participate: The Review Board approved waiving of obtaining informed consent from individual patients for this retrospective study.

Consent for publication: Consent for the publication of images obtained from the patients.

Competing interests: The authors declare no competing interests.

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